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Application of Economic Analyses to Hurricane Warnings to Residential and Retail Activities In the U.S. Gulf of Mexico Coastal Region

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ABSTRACT—Hurricane warnings cause people and businesses in the predicted path of the cyclone to take actions that will reduce damage and/or loss of life. Sometimes these actions and their attendant costs are avoidable, since a larger section of the coast is alerted than that which the hurricane actually affects.

Using general population densities and the average damage costs due to storms, the authors present a combined game- and decision-theory approach to estimating the economic benefits of more accurate prediction. The potential savings to this economic sector for a substantial improvement in 24-hr forecasting accuracies (that is, the reduction of the average forecast error to one-half its present value) is shown to be at least $15.2 million in the first year. A general equation is presented for various combinations of improvement levels, population densities, percentage of those who protect, and number of warnings per season.

1. INTRODUCTION

To protect or not to protect? To flee or not to flee? The coastal residential and small retail sector in hurricane areas depends on weather information in making these decisions. Good forecasting can result in better protection for business facilities, homes, and personal belongings, and, indeed, for the health of families.

Sugg (1967) showed that the average population density throughout the U.S. Gulf Coast area is nearly 2 million people for each 300 mi of coastline—and growing. Residential and commercial activities, including homes, apartments, motels, and small retail establishments, tend to remain in relatively stable value and proportional relationships to population data. We are concerned, then, with a lot of people and a lot of money and the savings in both that can result from better forecasting.

In 1966, the average annual damage resulting from hurricanes in this country was $300 million (Gentry 1966, Sugg 1967) and there has been an upward trend in this figure since then. Little attention has been given to categorizing these damages as industrial, commercial, and so forth. However, data adapted from a U.S. Army Corps of Engineers report on 1961 hurricane Carla (Cry 1962) does show that approximately 40 percent of the total damage in that storm resulted from wind and rain (as opposed to surge), and of that, 60 percent was damage to residential and commercial property and 40 percent to industrial, agricultural, government, or utilities operations. The 60-percent damage to residential and commercial property—or some $72 million—can be reduced if appropriate measures are taken. The level of this reduction has been estimated by a mutual insurance company (White 1971) to be about 15 percent, or $10.8 million.

Only 20 percent of the population, however, takes protective action (Sugg 1967), and some $8.64 million is lost unnecessarily. (Note that cost of protection must be subtracted for a net savings estimate). More accurate forecasts would not only yield greater savings for that part of the population that takes protective action but could also influence more people to take such action.

This should not be interpreted to mean that 80 percent of the population do not protect simply because they do not believe the forecasts. Other factors, including variations in income and education levels with corresponding differences in attitude toward risk and the range of protective activities likely to be engaged in by rental apartment-dwellers as contrasted with those of home owners, also influence the decision to protect and the proportion of those who will do so.

There is, however, a potential drawback to increased protection. As a greater percentage of the population protects, *over-protection* costs due to hurricane warnings will go up.

2. SCOPE

The nationwide collections of insurance claim association figures, personal interviews with Dade, Broward, and West Palm Beach Counties, Florida, insurance underwriters and claims men, and a sample of more than 30 interested individuals show that most retail establishments and residences will suffer severe and substantially unavoidable damage if surge-zone or flooding conditions prevail or if the property is in the direct path of a major hurricane. This study, then, treads the delicate path of identifying the damage that is *avoidable* under conditions in which *some* damage is inevitable. Therefore, we focus on wind and rain (usually water damage resulting from wind damage) as causes of at least partially avoidable damage for localities not in the direct path of the storm.

Potential "strike zone" treatment is restricted to timely and consistently accurate notification, to permit orderly movement of families and prized personal property to inland or storm fringe areas. Of course, some damage reduction is associated with appropriate pre-departure protection.

Indicated needs are:

1. Reliable and timely forecasts of wind intensity.
2. Improved forecast accuracy that would convince more of the population to take protective measures. In educational psychology terms, this would increase the slope of the learning curve. Such a curve shows the relationship between time and the percentage of the people that would give a correct response.
3. Direct-path warnings based on probabilities and the substantial costs of unneeded evacuatiou procedures.
4. Education on proper procedures for riding out a hurricane safely, for minimum construction standards, and for cooperative efforts with underwriters to reduce avoidable damage and, thus, casualty insurance protection costs.

3. COSTS OF PROTECTION

People usually make protection and, later, evacuation decisions well in advance of storm landfall. The cost of protection includes material expense plus labor for installation of shutters, grilles, plywood barriers, and tape on windows and glass doors. This labor charge can be substantial for retail establishments, since most storm shutters are not stored on the premises, and out-of-pocket charges, loss of retail trade, and lost personal and/or employee time all add to "business interruption" claims.

Since purely personal hazards are evaluated differently by each social, economic, and age segment of the population, no hard data on the costs of flight could be obtained. The decision to flee might be based on current bank balance, business considerations, hope of reducing uninsured casualty losses by remaining with owned property, and degree of confidence in the forecasts. Despite the increasing coastal population, there has been a year-by-year reduction in deaths from hurricanes. It seems logical, therefore, to conclude that a significant amount of money is being spent each year for flight from predicted hurricanes. No attempt has been made to predict this amount, but it would appear to be a productive area for future research.

4. STATISTICAL DATA

Assuming a linear relationship, we show in table 1 the damage reduction from various increases in the percentage of people protecting. Table 2 assumes a 10%-20%-60%-100% increase in acceptance of forecasts by those who do not now protect, using an annual population increase of 5 percent. A 100-percent increase in acceptance of forecasts will probably never be reached because of previously mentioned factors, other than confidence in the accuracy of the forecast system, that determine the percentage of the population that will protect.

TABLE 1.—*Damage reduction from increases in the percentage of people protecting*

Proportion of alerted population that takes protective action	Damage avoided
(%)	(millions of dollars)
20 (current)	2.16
40	4.32
60	6.48
80	8.64
100	10.80

TABLE 2—*Damage reduction with specified acceptance pattern and population growth*

	Proportion of new total population who protect properly	Damage avoided
	(%)	(millions of dollars)
year 1*	28	3.18
year 2	36	4.29
year 3	68	8.54
year 4	100	13.33

*Example of formula computation:

year 1 $(20+10\times 80\%)=0.28\ (1.05^{t})\ (10.8)=\$3.18$ million.

5. DAMAGE COST REDUCTION

A study of hurricane damage in Miami, Fla. (Demsetz 1962), estimated that wind and rain damage from a hurricane would be $13 million if the city received no warning, but only $7.7 million ($6.53 million damages and $1.17 million protection costs) if the city prepared for the storm. The sizeable reduction in damage when appropriate action is taken is not a contradiction of the 15-percent figure used previously if one recalls that the above estimates are for wind and rain damage only. These will be useful figures for estimates of damage reduction (but not total damage) since the greatest potential saving lies in this wind-rain damage area. Potential validation of these estimates might come through Insurance Claims Association [1] figures based on lower claims (wind damage and consequential damages are "insured perils" but surge and flooding damage is generally not covered).

6. AN "INDIFFERENCE" MODEL

A game box for the interpretations of responses to forecast warnings is shown below.[2] Patterned after that of Nelson and Winter (1964), it expresses the above costs on a per capita basis.

	H	H'
A	$26,460/1,000 people	$4,000/1,000 people [3]
A'	$44,673/1,000 people	0

[1] Mention of a commercial organization does not constitute an endorsement.
[2] H is hurricane; H' is no hurricane; A is action is taken; A' is no action is taken.
[3] This value corresponds with Miami data.

TABLE 3—*Damage reduction in selected cities*

Area	Population 1971	Probability of hurricane	Lowest expected cost without forecast	Expected cost with perfect forecasting	Gross potential (maximum) savings
Brownsville, Tex.	137,000	0.08	$489,616	$290,002	$199,614
Galveston & Houston, Tex.	1,888,000	.13	10,964,541	6,494,342	4,470,199
Lake Charles, La.	142,000	.06	380,614	225,439	155,175
New Orleans Parish, La.	585,000	.12	3,136,044	1,857,492	1,278,552
Panama City, Fla.	73,000	.07	228,279	135,211	93,068
Tampa & St. Petersburg, Fla.	484,000	.06	1,297,304	768,398	528,906
Miami (Dade & Broward Counties), Fla.	1,871,000	.15	12,537,477	7,425,999	5,111,478
Total					$11,836,992

Assuming a proportional similarity in figures for all areas, cost reduction for any locality can be estimated. Simply multiply each cell by the population, in thousands, of that locality and calculate the expected value of each alternative using the climatological probabilities of hurricane occurrence in that region. These probabilities can be found in Simpson and Lawrence (1971).

New Orleans Parish, La., for example, has a 1971 population of 585,000 (Long 1971) and the probability of a hurricane striking it in any year is 0.12. The game box for this would be

	H	H'
A	\$15, 479, 100	\$2, 340, 000
A'	\$26, 133, 705	0

The expected cost of protecting all the time is

$$0.12\ (\$15{,}479{,}100)+0.88\ (\$2{,}340{,}000)=\$3{,}916{,}692,$$

and the expected cost of taking no action is

$$0.12\ (\$26{,}133{,}705)=\$3{,}136{,}044.$$

With no forecasting (assuming people would not protect), the expected annual cost would be \$3,136,044. With perfect forecasting, the area would protect only when a storm is inevitable, reducing the expected cost to 0.12 (\$15,479,100), or \$1,857,492—an annual savings of \$1,278,552. Since the area *does* protect to some extent during the year, the real potential savings is something less than the \$1,278,552 figure.

Table 3 presents basic data and results from studies of selected areas along the gulf coast States. The \$11.84 million figure is an upper estimate of the potential savings when the entire population takes proper action based on perfect forecasting. Some portion of this is already being realized, by that percent of the population that already protects, and only a part of the total (some 24 percent) represents savings to residential and retail segments of the economy.

TABLE 4.—*Projected savings for the selected cities*

Year	Proportion that protects	Savings from perfect forecasts	
		Total	Wind and rain damage to residential and commercial property
	(%)	(millions of dollars)	
Base	20	1.18	0.28
1	28	1.64	0.40
2	36	2.37	0.57
3	68	4.67	1.12
4	100	7.30	1.75
		4-yr total benefit	3.84

Table 4 shows the gross savings over a 4-yr period (on a 10–20–60–100-percent learning curve demonstrating increasing response to the forecast) incorporating a 5-percent annual population growth factor. In constructing the table, we assumed that 50 percent of the maximum savings is currently being realized.

7. GENERALIZATION OF THE MODEL

A hurricane game box has the general form

	H	H'
A	$\alpha L+C$	C
A'	L	0

where C is the cost of protection, L is loss due to hurricane damage, and α is the proportion of L that is inevitable, even with protection.

If P_1 is the probability of a hurricane striking the area at any given time, then a forecast of "hurricane" should be given *only* when

$$[P_1(\alpha L+C)+P_2C]<P_1L$$

where $P_2=(1-P_1)$. This can be simplified to

$$P_1>\frac{C}{(1-\alpha)L}.$$

A forecaster watching a hurricane should not, therefore, predict a "strike" area until his estimate of the probability of the hurricane landfall being there is greater than $C/(1-\alpha)L$. As an alternative, he might simply give the probability that a hurricane will strike, and allow each individual in the area to decide whether or not to protect, based on C, L, and α values appropriate for the area.

Using the figures from Demsetz (1962), the "indifference" probability, P_1, for Miami is 0.1809. This value is given as an example only; much more study is needed for individual areas using pertinent data on the breakdown of hurricane damages and on the costs of protection for various types of economic activities there.

The above analysis considers only those costs that can bn measured in strictly economic forms. With human lives at stake, perhaps some level of P_1 *less* than $C/(1-\alpha)L$ might be chosen as a cutoff point. On the other hand, however, an error in forecasting may decrease the credibility of future forecasts; it might, therefore, be better to choose a cutoff point of P_1 *greater* than $C/(1-\alpha)L$. Such a value judgment is beyond the responsibility of these researchers.

8. BENEFITS OF STATISTICAL IMPROVEMENT IN FORECASTS

The absolute values of the difference between observed and forecast position (mean position error) and the position error standard deviations have been recorded for hundreds of hurricanes, yielding thousands of forecasts. These are used by the National Hurricane Research Laboratory to evaluate forecasting techniques and by the National Hurricane Center to provide "minimum regret" warnings to coastal areas in the path of a hurricane.

The mean position error (MPE) and standard deviation, $\hat{s}$, for the official National Weather Service 24-hr forecast (which corresponds to a sufficient warning period for the residential and small-retail segment of the economic population being studied) are 144 n.mi. and 100 n.mi., respectively (Tracy 1966).[4]

The 24-hr warnings must be given to a coastal zone that will include, to a high probability, the area of *actual* hurricane landfall. With this MPE and $\hat{s}$ and a 95-percent confidence level (i.e., five times out of 100 the hurricane fringes will make landfall *outside* the stated warning zone), the warning zone for an average hurricane (highest winds over 74 kt across a diameter of 100 n.mi., and lesser but still destructive winds to a diameter of 250 n.mi.) is 200 n.mi. on either side of the 250 n.mi.-wide path estimate of landfall (forecast).[5] A swath at least 650 n.mi. wide will, therefore, be included in the warning zone.

Often called the "overkill" factor, the size of the safety zone in which most damage can be avoided by routine protective measures—or that may never feel the edge of the storm—reflects the uncertainties inherent in the present state of the forecasting art. The entire zone receives the warning and is under essentially the same uncertainty as to the need for protection or flight. As a result, the population becomes convinced that "it won't happen here" and only 20 percent of the warning zone's population takes any action. For most of those who do take action, the precautions are an unnecessary expense. This same uncertainty of forecasting leads, conversely, to sizeable (and avoidable) losses incurred by residents who are, in fact, in the storm's path, but who take no protective action.

With a perfect forecasting system, the warning zone and the hurricane landfall path are the same. If confidence in such a forecasting system were strong, practically all retail establishments and coastal zone residents would, where economically feasible, take protective action, incur protection costs, and benefit from the reduction in damage that protection offers. As a result, practically all unneeded protection costs, and avoidable losses, would be eliminated. In the real world, and without any certain way to evaluate the improvement that combinations of new technological or theoretical advances will provide (as a reduction to MPE and $\hat{s}$), the mathematical technique known as parametric programming leads to a statement of "conditional" benefits. Data on such hypothetical improvements are given in table 5.

TABLE 5.—*Theoretical reductions in the width (n.mi.) of the warning zone and in overprotection costs (millions of dollars) as a result of improved forecasts*

$\hat{s}$ \ MPE	144	135	125	110	100	90	80	70	60	50	40	30	20
100	401	392	382										
	$2.64	$2.58	$2.51										
93		373	363	348									
		$2.45	$2.39	$2.30									
81			333	318	308								
			$2.20	$2.09	$2.03								
74				300	290	280							
				$1.97	$1.91	$1.84							
67					261	251	241						
					$1.72	$1.65	$1.59						
59						241	231	221					
						$1.59	$1.52	$1.46					
52							214	204	194				
							$1.41	$1.34	$1.28				
44								184	174	164			
								$1.21	$1.15	$1.08			
37									155	145	135		
									$1.02	$0.95	$0.89		
30										126	116	106	
										$0.83	$0.76	$0.70	
22											97	87	77
											$0.65	$0.57	$0.51
15												68	58
												$0.45	$0.38

Use of the Table

Table 5 is based on a 95-percent confidence level. The size of the warning zone on either side of the expected path of destruction must be determined. Using an average NWS 24-hr forecast, MPE of 144 n.mi. and $\hat{s}$ of 100 n.mi. would mean alerting a region of 200.5 n.mi. on either side.

[4] Statistics for the 1967–72 hurricane seasons indicate some improvement in the 24-hr official forecast, with an MPE of 122 n.mi. (Tracy 1972). No standard deviation value was available.

[5] NHRL dispersion plots show that the patterns are actually somewhat elliptical (Tracy 1966) but Kolmogorov-Smirnov tests for maximum deviations between observed data and an orthogonal bivariate normal distribution find them negative. That is, the hypothesis of random normal distribution for error vectors resolved into latitude and longitude components cannot be rejected.

NHRL personnel (Tracy 1971) agreed that, for purposes of sensitivity analysis (both from the standpoint of NHRL practice and the obvious convenience for computation), a univariate normal distribution is reasonable. Tracy provided MPE and $\hat{s}$ data for the 23 forecasts from the 1970 season, in latitude-longitude components, using the NHRL 67 forecasting model as the basis for prediction. The longitude (east–west) component MPE was −71.5 n.mi. with an $\hat{s}$ of 84.9 n.mi., and the latitude (north–south) component MPE was +36.8 n.mi. with an $\hat{s}$ of 65.9 n.mi. These components correspond to an MPE (one sided) of 80.4 n.mi. (or a 160.8-n.mi. diameter circle) and an $\hat{s}$ of 108 n.mi., approximately corresponding to the average data being used in this study.

This region's population density, the cost of protection, and the estimated fraction of those who protect, can be used to determine "overprotection" costs—in this case \$2.64 million.

One can use table 5 to determine the gains from more accurate forecasting by subjectively choosing lower MPE and $\hat{s}$ values. For conjectural purposes, assume that a combination of new forecasting methods would result in a two-fold improvement (new MPE and $\hat{s}$ values one-half their present size), then choose the "new" argument, MPE=70 n.mi. and $\hat{s}=52$ n.mi., and read the overkill zone as 204 n.mi. and the unneeded protection cost as \$1.34 million. Comparing this with 401 n.mi. and \$2.64 million, we derive a savings of \$1.30 million.

Statistical Simplifications

MPE is the average value (in n.mi.) of the absolute difference between observed and forecast positions. The probability is 0.50 (or 50 percent) that a hurricane's position 24 hr in the future will be within a circle of MPE diameter. If the distribution of MPE is a random variable with a univariate normal distribution, this corresponds to a value of $\pm 0.675\ \hat{s}$.

MPE and $\hat{s}$ data do not correspond exactly with theoretical distribution data. Therefore, 10-n.mi. MPE "steps" on either side of the theoretical "$\hat{s}$ given MPE" values are given in table 5 to show range of cost with MPE as a function of a given $\hat{s}$.

Although the dispersion errors are circular, we have treated only the lateral (sideways direction) difference and ignored the pathwise (slow or fast) dispersion.[5] We have also assumed that MPE, $\hat{s}$, and size of the storm are statistically independent. This is undoubtedly an oversimplification, but seems to yield satisfactory results for these purposes.

Protection costs on a per capita basis are estimated to be \$4.50 per hurricane protected against (i.e., \$18 per family of four). Studies of the Miami area (Demsetz 1962) indicated a figure of \$4,000/1,000 inhabitants—almost entirely residential, small retail, and commercial economic units since Dade and Broward Counties at that time contained little industry. Sugg (1967) has a more current estimate of \$5,000/1,000 inhabitants, a figure that may contain some industrial cost segment. Considering dollar depreciation since the 1962 study, the choice of \$4.50/inhabitant seems reasonable, if not analytically precise.

We wish to emphasize that table 5 was constructed to show conjectural, or "what if?" data, and is not a prediction of expected improvement in forecasting—except, perhaps, for purely subjective speculation about optimal improvement from the economic standpoint. Subsequent investigators might use this table to estimate the effect of various combinations of sensor accuracies, grid patterns, and other data and economic factors. It seems reasonable, also, that different economic segments of the U.S. gulf coast region could be similarly analyzed, and avoidance-cost-accuracy tables could be generated.

The combination of this approach with the general indifference probability argument of the previous section (resulting, for the Miami example, in an indifference probability of 0.1809) could lead to a revision of the confidence level chosen—perhaps to 82 percent—with a corresponding reduction in the overkill associated with a forecast. However, such an examination is beyond the scope of this study.

9. CONCLUSIONS

Better forecasting would result in gains in two areas, reduced damage and cost avoidance.

Reduced damage is a function of:

1. The number of people who protect.
2. Improvement in forecast accuracy and choice of confidence interval, $\hat{t}$.
3. Fraction of damages in the residential/small retail sector.

A 15-percent reduction in wind and rain damage is possible; that is, a saving of \$10.8 million annually.

Costs are avoided in three ways. The first, cost avoidance from overkill (i.e., elimination of the cost of unnecessary protection), is a function of:

1. The number of people who protect.
2. The cost of protection.
3. Improvement in the forecast accuracy and the choice of $\hat{t}$.
4. The number of hurricane landfalls per season.
5. Economic and social indifference probabilities.

Savings of up to \$2.0 million per hurricane warning per sector are possible. The second cost-avoidance factor, elimination of the cost of unnecessary flight for personal safety, is a function of:

1. The number of people who flee.
2. Improvement in forecast accuracy and choice of $\hat{t}$.

The third cost avoidance factor, the reduction in casualty insurance premiums, is a function of:

1. Proportion of population that protects.
2. Improved accuracy of forecasts.
3. Reduced casualty claims.

The monetary gains from the last two factors have not been estimated.

A formula that shows combined reduced damage and cost avoidance benefits is:

$$\text{annual benefit}= \lambda \left\{ \$10.8 \text{ million} + \frac{\$0.0329 \text{ million}}{\text{nautical mile}} \times [401 \text{ n.mi.} - \text{new overkill (n.mi.) for improved system}] \times \text{No. of landfall warnings per season} \right\}$$

where λ is the population proportion protecting $(0 \leq \lambda \leq 1.0)$ and 401 n.mi. is the overkill for MPE=144, $\hat{s}=100$, $\hat{t}=\pm 1.96\hat{s}$.

If we assume the conjectural accuracy improvement to approximately one-half the present error (i.e., MPE=70, $\hat{s}=52$, $\hat{t}=\pm 1.96\hat{s}$) and 10 landfalls a season, the savings

TABLE 6.—*Benefits to U.S. Gulf of Mexico region resulting from a 50-percent reduction in forecast error*

Year	Proportion that protects	Savings from improved forecasts
	(%)	(millions of dollars)
1	28	21. 489
2	36	27. 998
3	68	57. 380
4	100	88. 570
	Total Savings	195. 437

are $15.2 million for the 20 percent who now protect. If in turn we assume that the population grows 5 percent annually, that other cost and frequency assumptions remain valid, and that the 10–20–60–100-percent learning curve occurs over the 4 yr following improved forecasting system activation, then the aggregate (reduced damage and cost avoidance) benefits will be as shown in table 6.

10. RECOMMENDATIONS

Climatological data and forecast records are very important for evaluating improvements in forecast accuracy. But just as important is the relationship between damage costs and protection costs because they can be used to define how accurate a forecast needs to be.[6] We recommend that complete records of costs, for both damage and protection, should be gathered and analyzed for each distinguishable geographic area of the United States. Such costs should be classified by economic segment, such as residential, retail, transportation, communication, power transmission, industry (with appropriate subcategories depending on the area), and government operations, and so forth. This information, when combined with climatological records and the state of the forecasting art, can be used to produce the optimal ("minimum regret") forecast.

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[6] For an earlier statement of this sort of analysis, see Thompson and Brier (1955).

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